PH-107

Quantum Physics and Applications

Motivation and Introduction

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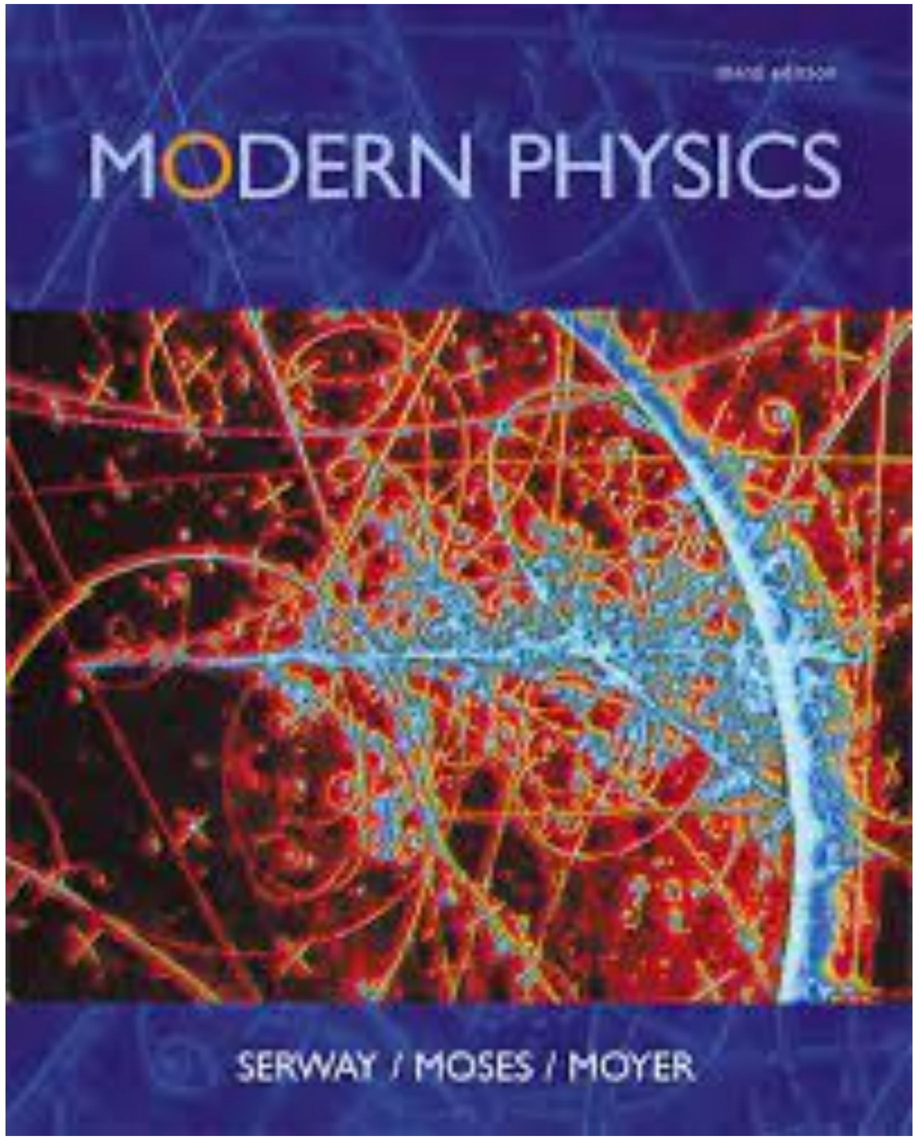
Reference Book:

Modern Physics: R. A. Serway, C. J. Moses, C. A. Moyer,

Thomson Learning Inc. 2005 Third Edition



Why do I learn Quantum Physics?

- Not only teaches some newer concepts of Physics but also teaches us to think beyond our existing knowledge.

- We have to stretch our imagination beyond our current thinking.

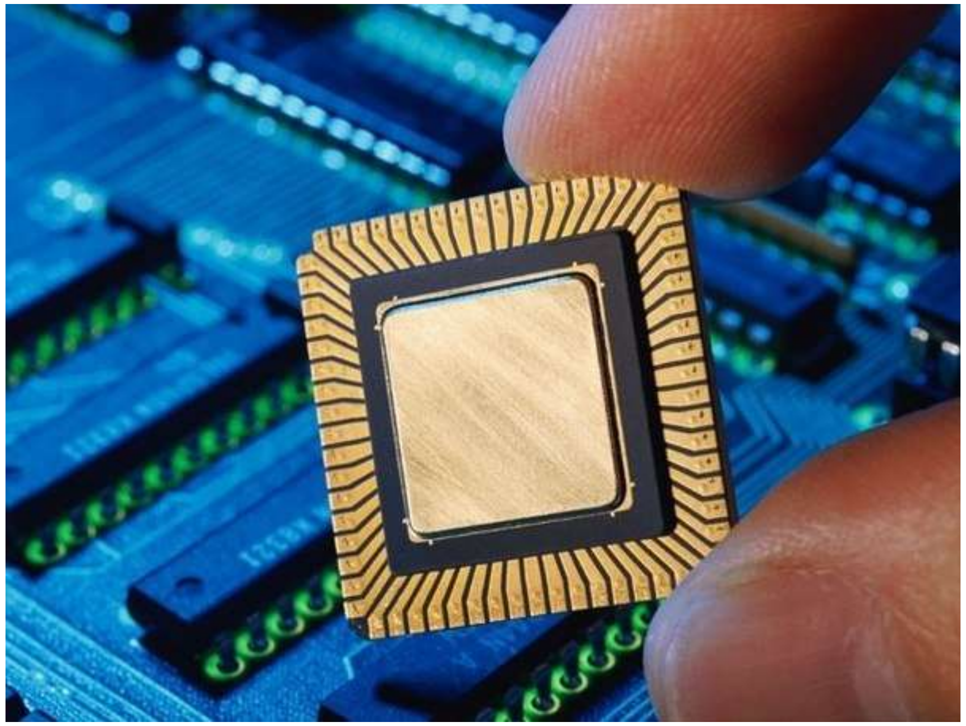
Why do I learn Quantum Physics?

Every student and practitioner of science and engineering need it.

You can not afford to ignore it.

If you understand it well, you can participate in the science and technology endeavors of 21^{st} century.

Why do I learn Quantum Physics?



Electrical & Electronics Engineering

- Semiconductor devices
- Nanoelectronics: Nanometer sized quantum tunnelling devices
- Spintronics: Devices based on electron spin
- Photonics: Devices based on photons

Why do I learn Quantum Physics?

Quantum tunnelling is how flash drives erase their memory

Giant magnetoresistance is what allows hard disk drives to function

Quantum wells are what allow lasers and photonics

Why do I learn Quantum Physics?

From Electrical Engineering to Quantum Physics: The Case of Nishina Yoshio

Kenji Ito

Sokendai University

In this paper, I examine connections between electrical engineering and quantum physics research in Japan. Japan was one of the countries that have successfully developed quantum physics research relatively early outside Europe and North America. This paper is a part of a larger project to aim to explain how this happened. I claim that electrical engineering was one of the bases for quantum physical research to be motivated, legitimized, and sustained. It also prepared at least one important figure in quantum physics research in Japan through its conceptual affinity.

"In this paper, I examine connections between **electrical engineering and quantum physics research** in Japan. Japan was one of the first countries that have successfully developed quantum physics research relatively early outside Europe and North America.

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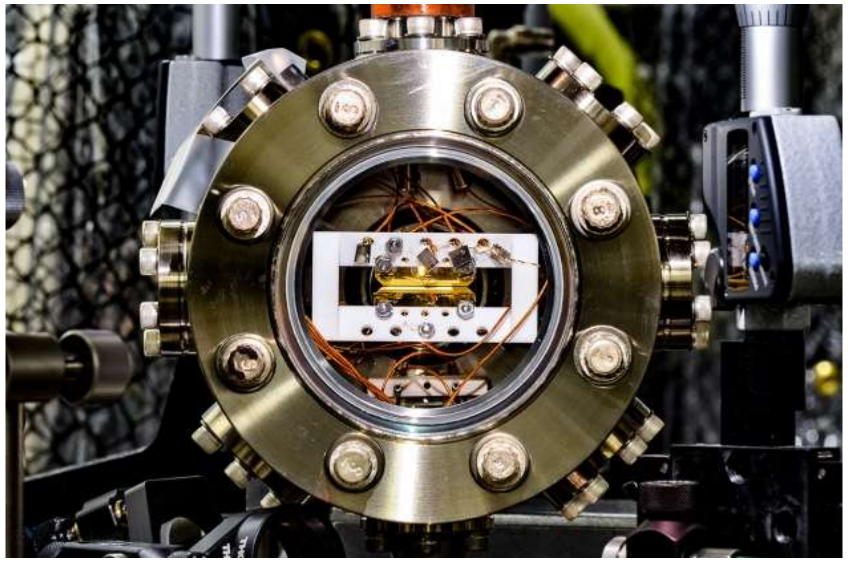
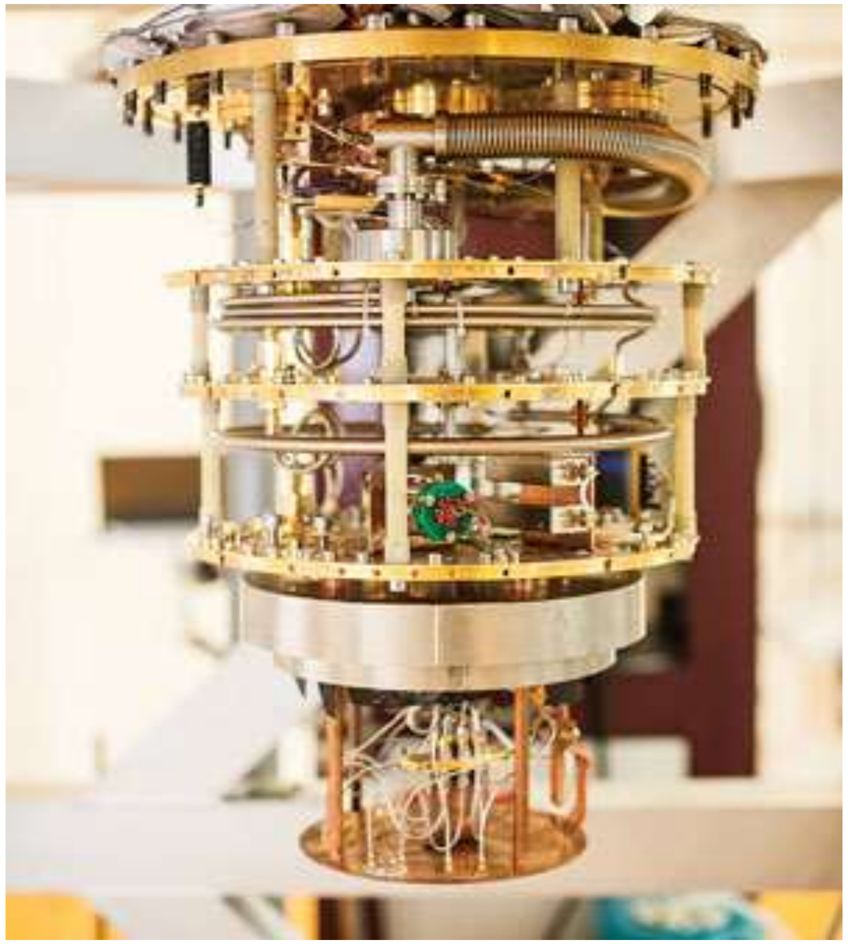
Why do I learn Quantum Physics?



Computer Sciences & Engineering



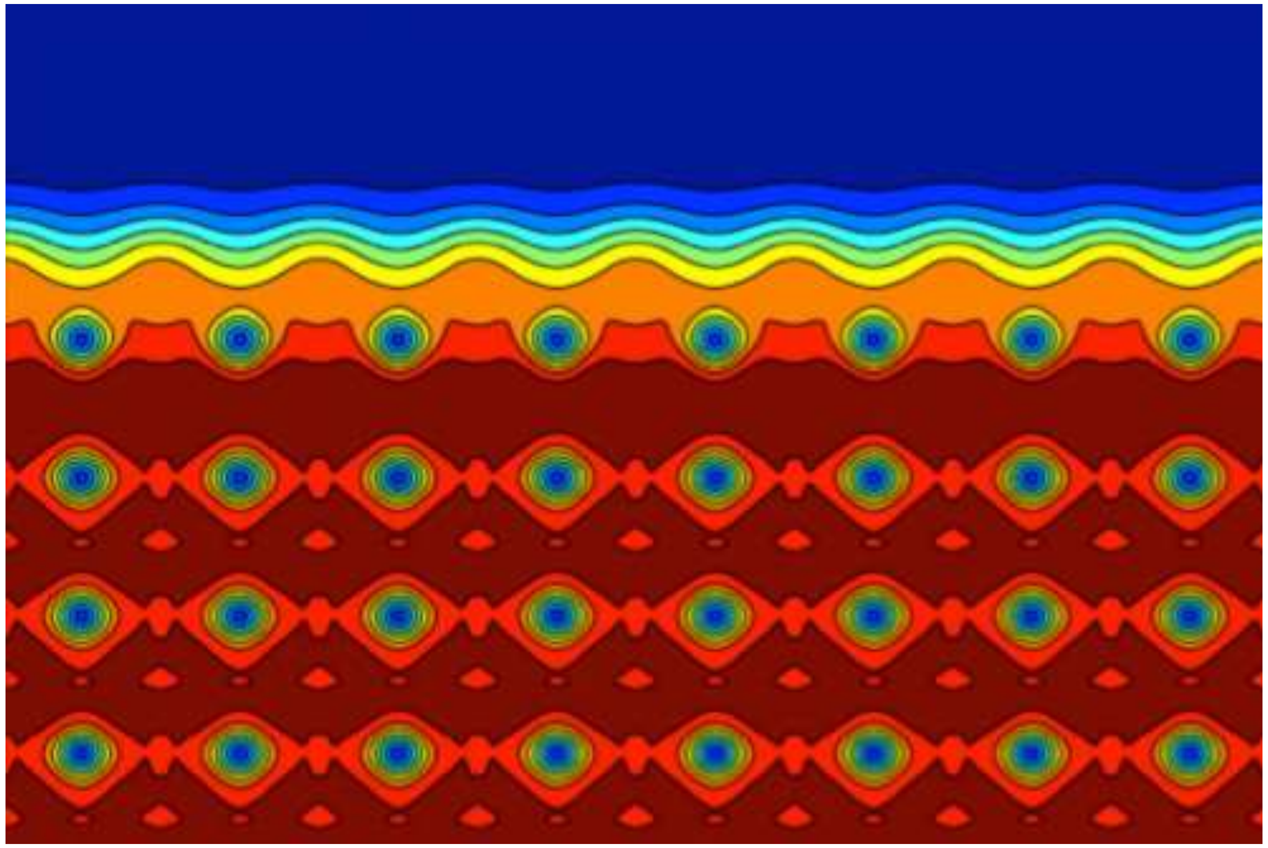
Quantum Computer & Quantum Information Processing

Cool Quantum Tech: This dilution refrigerator can cool quantum dots to less than 5 millikelvins for experiments in quantum computing.

Why do I learn Quantum Physics?

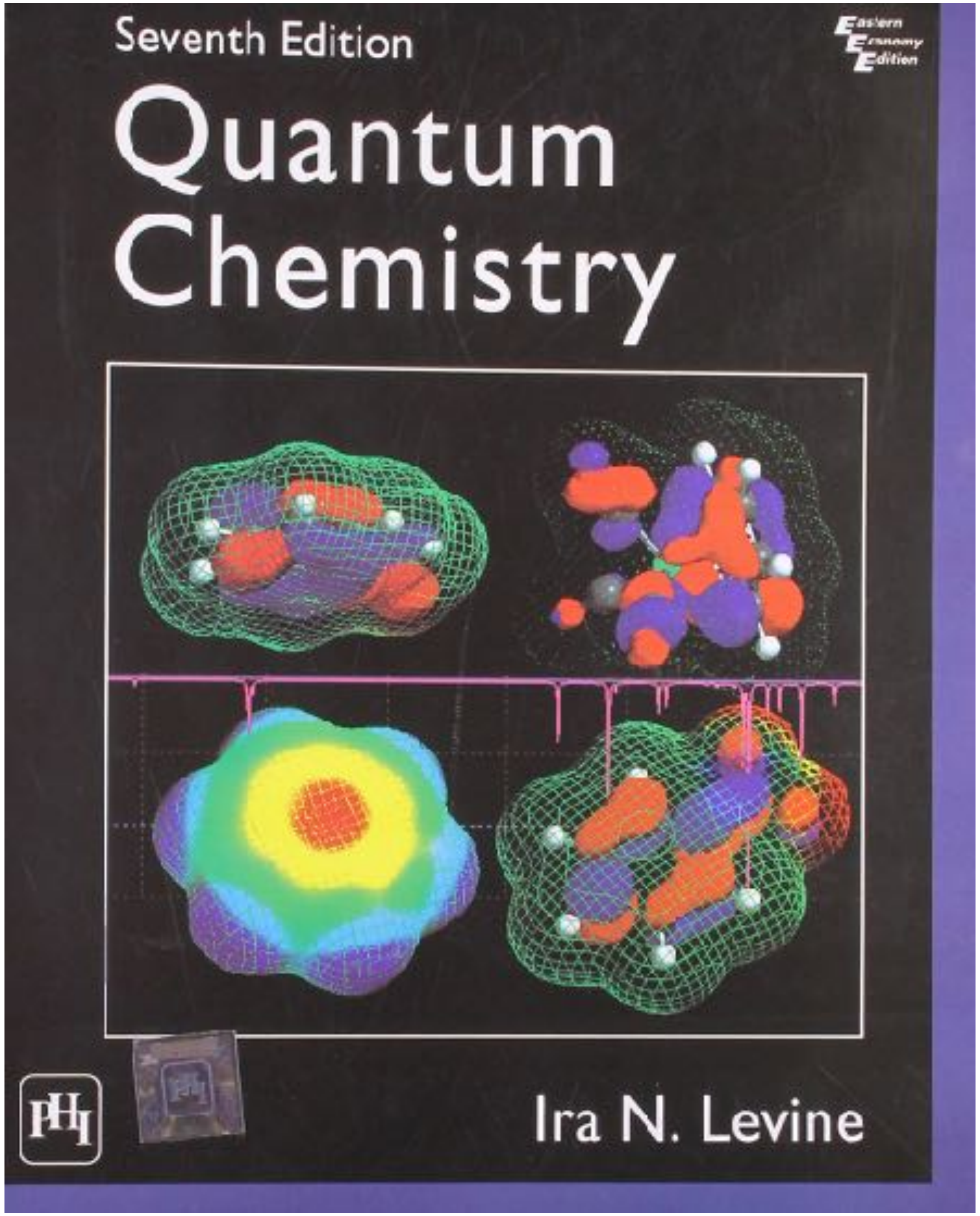
Caltech: Department of Mechanical and Civil Engineering

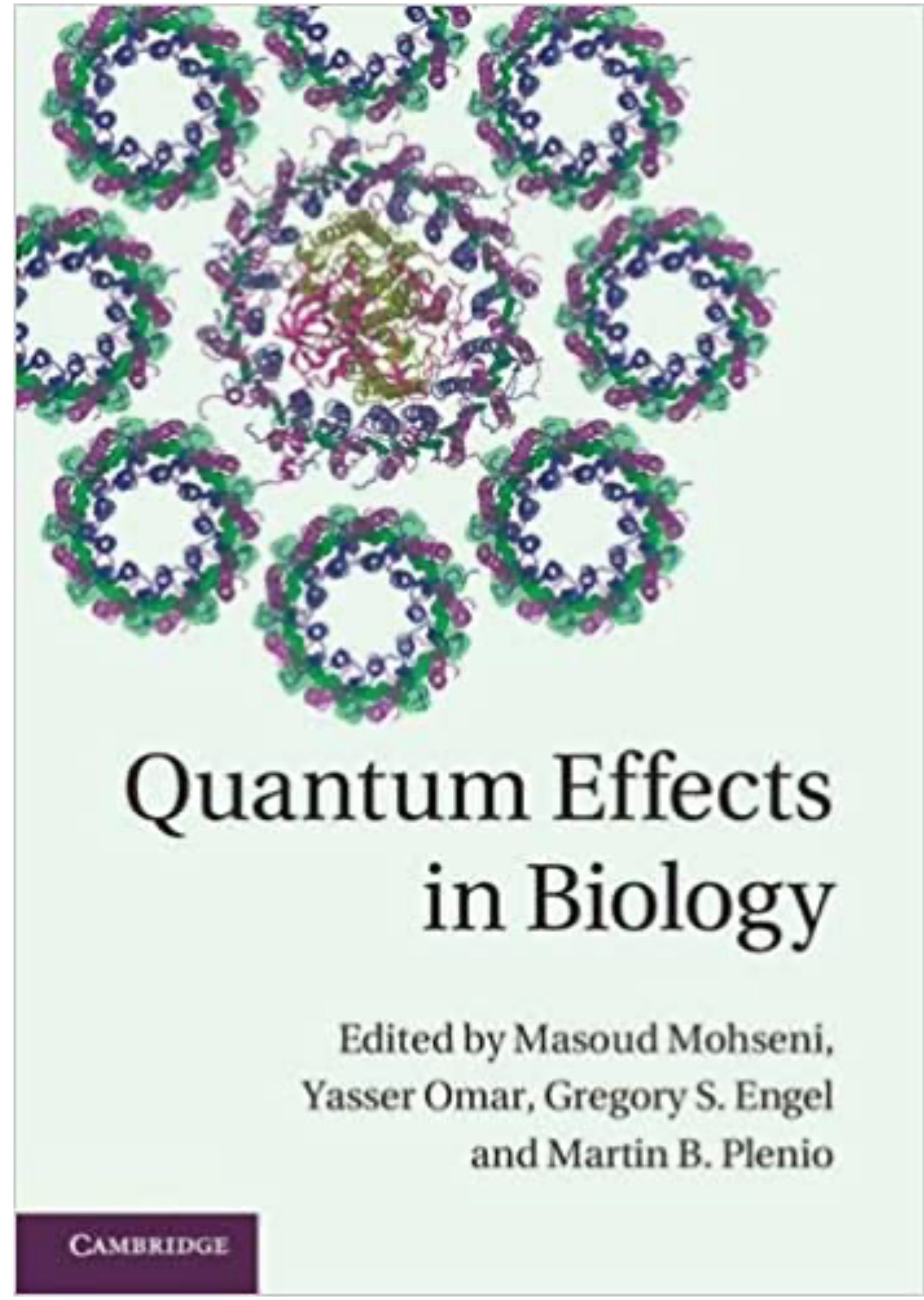
Quantum Mechanics at the Macroscopic Scale:
Coarse-graining Density Functional Theory



Multiscale Modelling

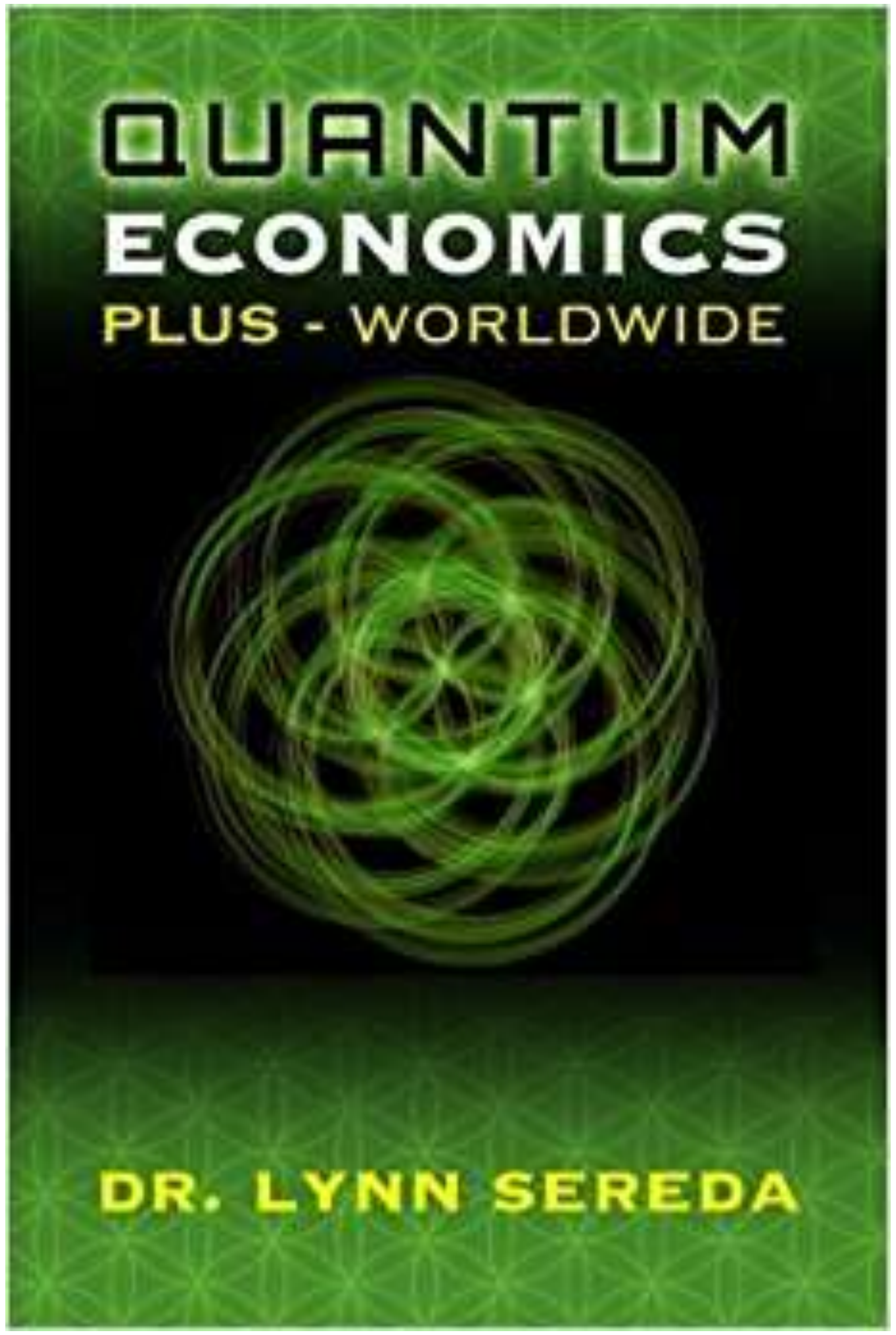
Why do I learn Quantum Physics?

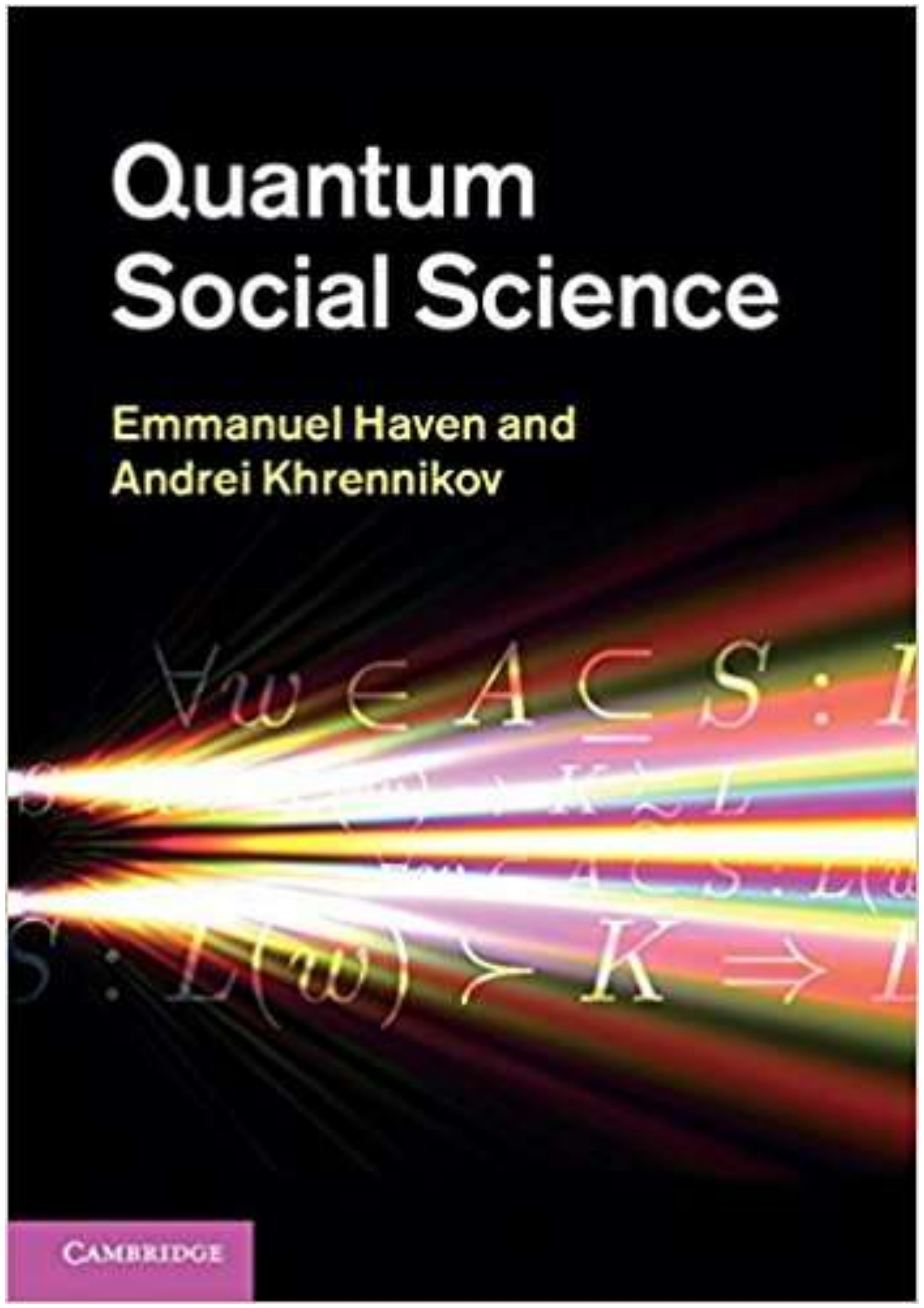




Why do I learn Quantum Physics?

Even the financial markets need knowledge of Quantum Physics!





Quantum Physics in Daily Life:

✳Toasters
✳Fluorescent Lights
✳Computer and Mobile Phone
✳Biological Compass
✳Transistor
✳Laser
✳Microscopy
✳Global Positioning System (GPS)
✳Magnetic Resonance Imaging
✳Telecommunication

Three Ways Quantum Physics Affects Your Daily Life:

Chad Orzel in Forbes

Learning Objectives:

✳Gives a flavor of Quantum Physics and its application to Solid State Physics.

✳To give some insight on how well established theories in Physics gave way to newer (Modern) theories.

Why Quantum Physics was needed at first place?

Theory which questions the "Wave ONLY" nature of light (electromagnetic wave)

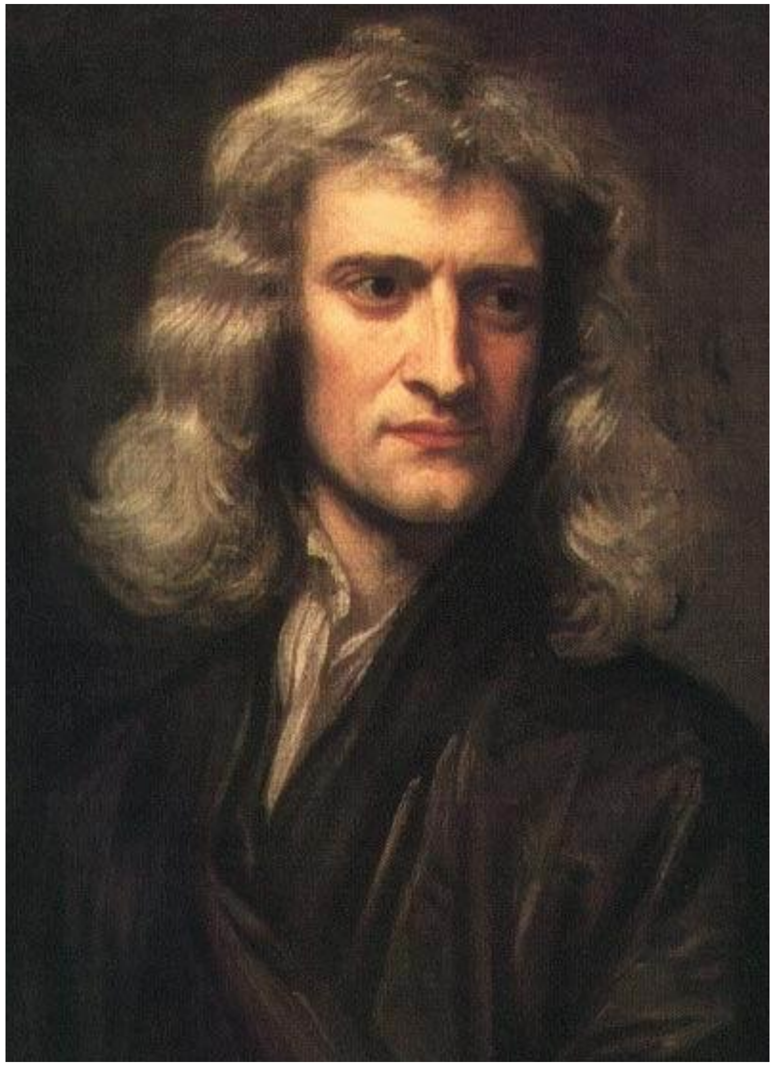
Birth of Quantum Physics (Quantum Mechanics)

What is Light?

Christiaan Huygens (1629-1695)

light consists of waves

Huygens' principle gave explanations of reflection and refraction, being based solely on the so-called of secondary wave fronts.



Sir Isaac Newton (1643-1727)

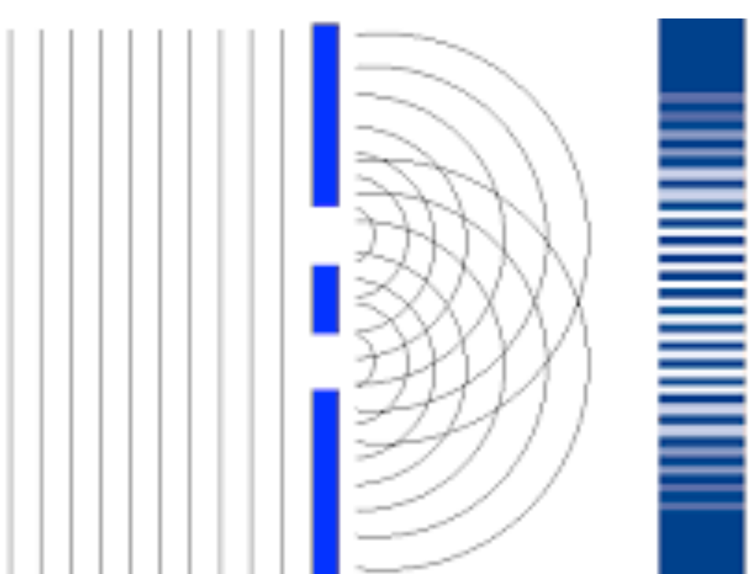
light consists of particles

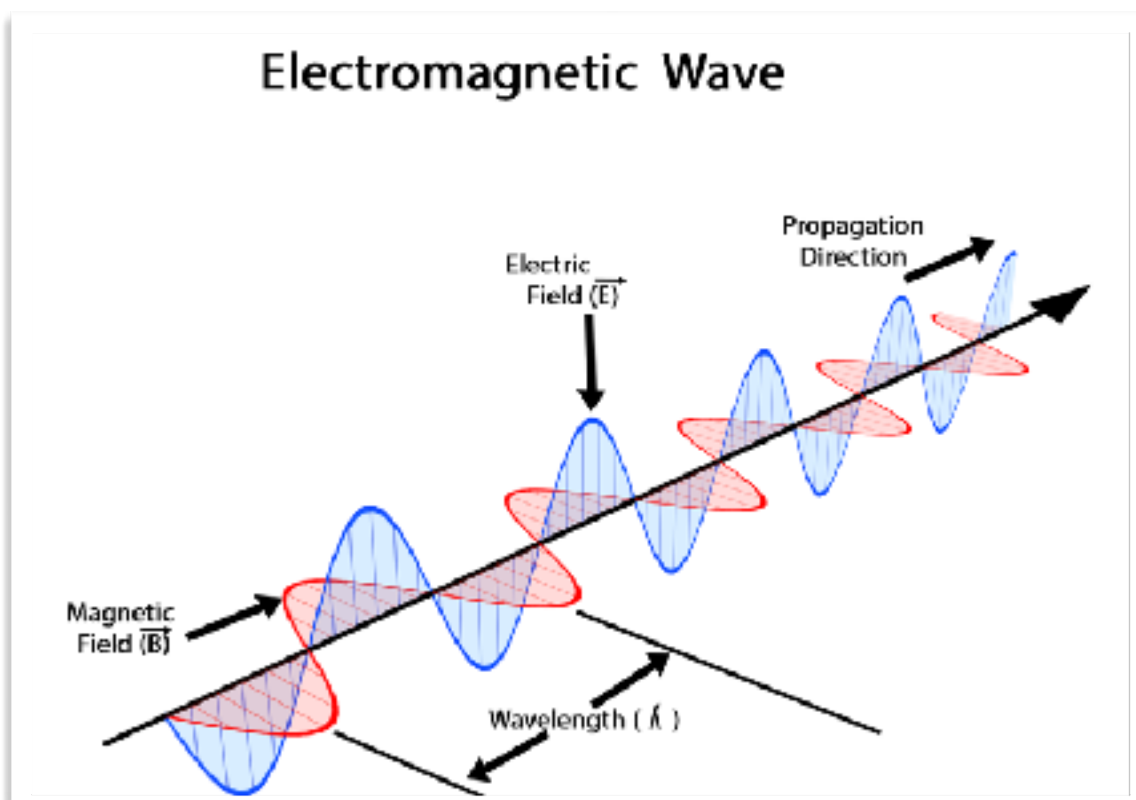
light consists of material corpuscles in motion

Thomas Young (1773-1829)

James Maxwell (1831-1879)

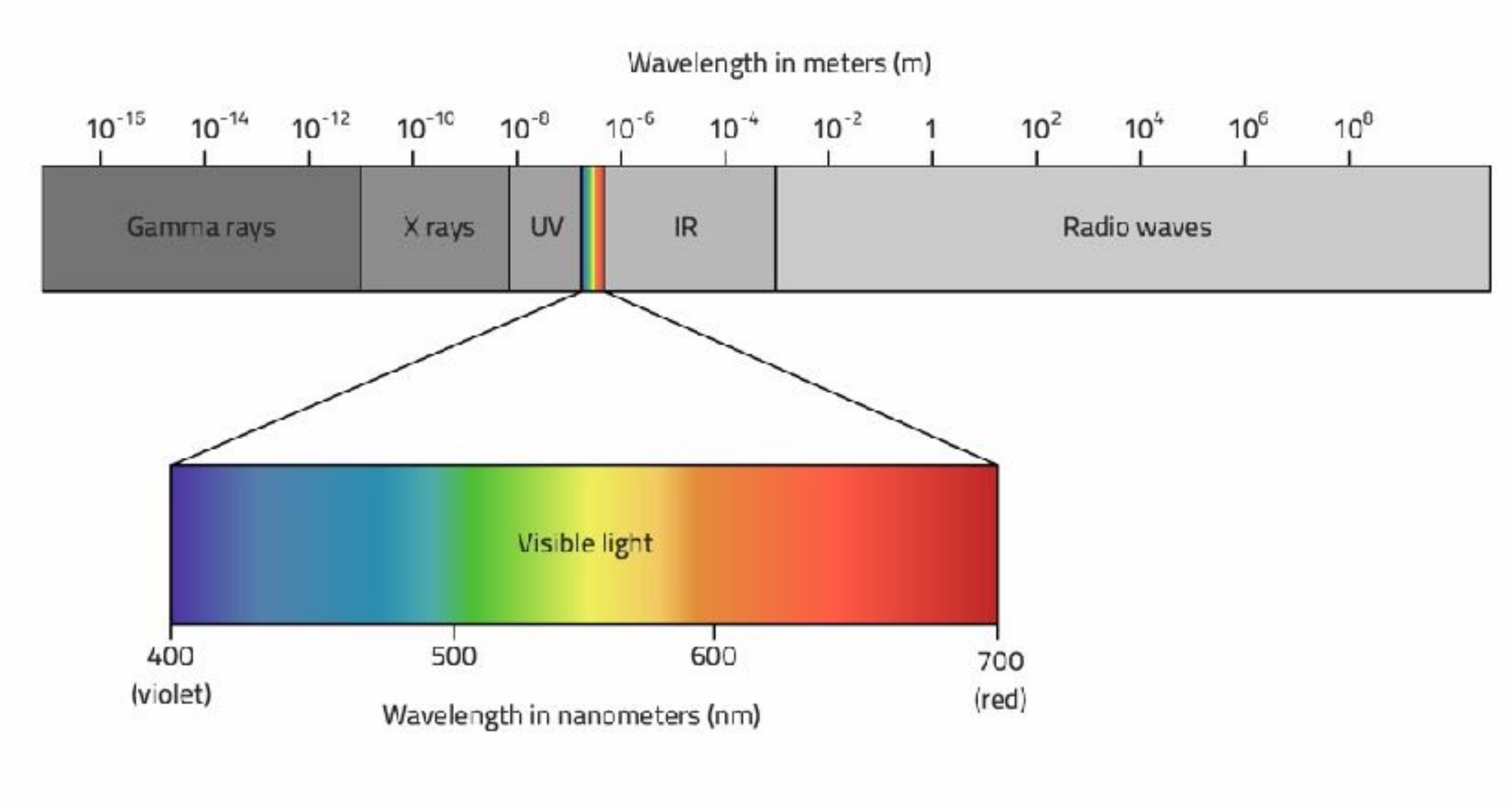
Maxwell's Equations (1860)





$$v = c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

What is Light?



EM waves can be reflected, refracted, and diffracted and they obey the **principle of superposition.**

So, indeed electromagnetic wave is light and vice-versa.

Quantum Theory (1901)

By 1900, some discoveries were NOT explained by the "Classical Theory".

- **Black-body radiation (**1860-**1901)**
- **Photoelectric Effect (**1887-**1905)**
- **Hydrogen Spectra (**1888-1913**)**

Black-body Radiation (1860-1901)

Recap from XI class

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CHAPTER ELEVEN

THERMAL PROPERTIES OF MATTER

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11.9.3 Radiation

11.9.4 Blackbody Radiation

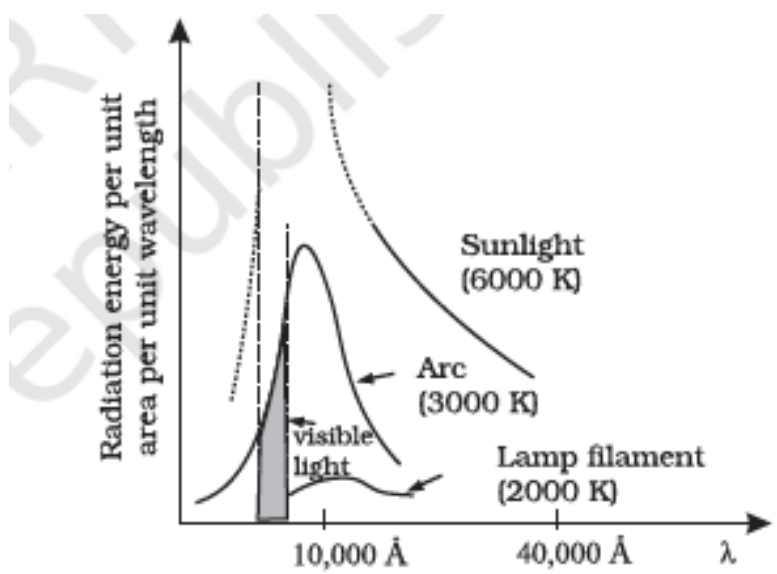


Fig. 11.18: *Energy emitted versus wavelength for a blackbody at different temperatures*

Gustav Kirchhoff (1824-1887)

temperature. The relation between λ_m and T is given by what is known as **Wien's Displacement Law**:

$$\lambda_m T = \text{constant} \qquad (11.15)$$

Black-body Radiation (1860-1901)

temperature. The relation between λ_m and T is given by what is known as **Wien's Displacement Law**:

$$\lambda_m T = \text{constant} \quad (11.15)$$

temperature. For a body, which is a perfect radiator, the energy emitted per unit time (H) is given by

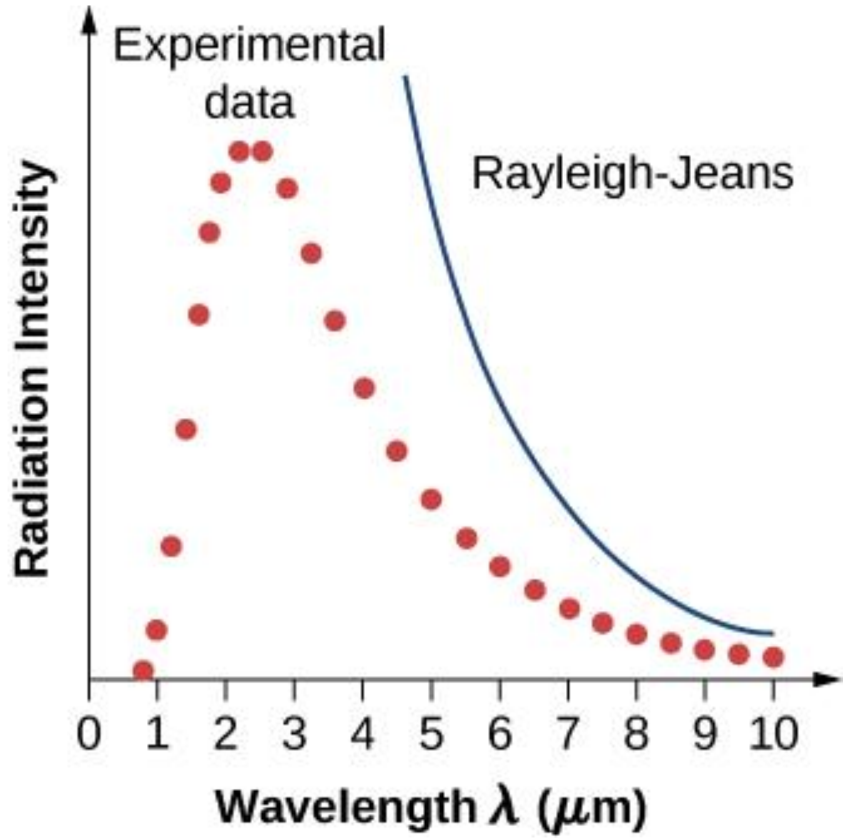
$$H = A\sigma T^4 \quad (11.16)$$

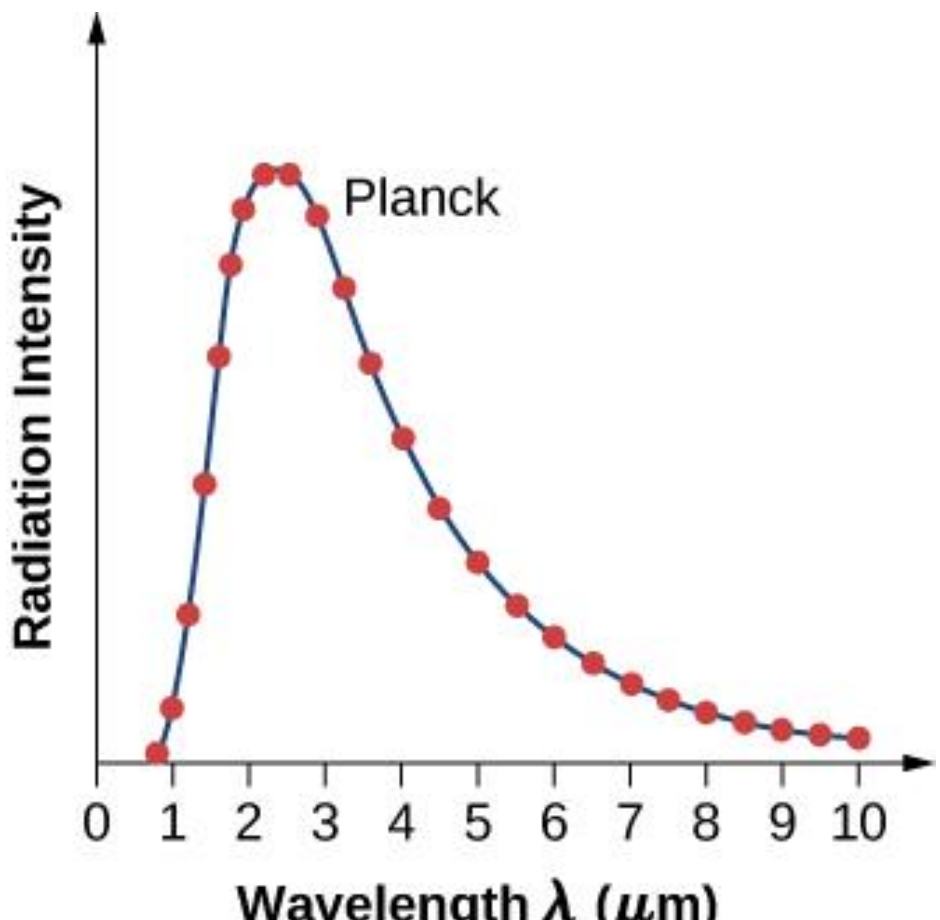
where A is the area and T is the absolute temperature of the body. This relation obtained experimentally by Stefan and later proved theoretically by Boltzmann is known as **Stefan-Boltzmann law** and the constant σ is called Stefan-Boltzmann constant. Its value in SI units

The most significant feature of the blackbody radiation curves in Fig. 11.18 is that they are *universal*. They depend only on the temperature and not on the size, shape or material of the blackbody. Attempts to explain blackbody radiation theoretically, at the beginning of the twentieth century, spurred the quantum revolution in physics, as you will learn in later courses.

Black-body Radiation (1860-1901)

Rayleigh–Jeans (1900): "Sources of radiation are atoms in a state of oscillation (classical oscillators)"





Max-Planck (1901): "The elementary oscillators could emit and absorb EM radiation ONLY in discrete packets"

$E = nh\nu$ $\quad$ $h \sim 6.6 \times 10^{-34}$ **SI units**

Birth of Quantum Physics !!

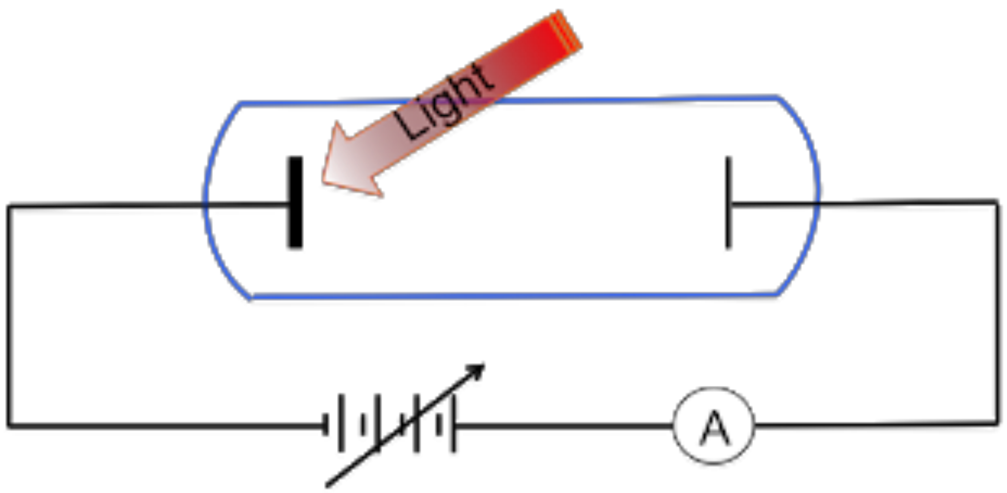
Black-body Radiation (1860-1901)

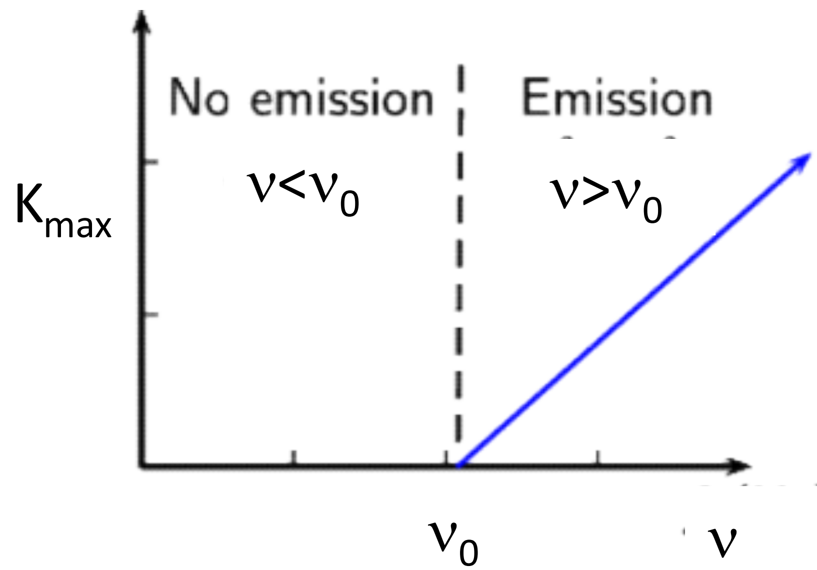
Max-Planck (1901): "The elementary oscillators could emit and absorb EM radiation ONLY in discrete packets"

$$E = nh\nu \qquad h \sim 6.6 \times 10^{-34} \text{ SI units}$$

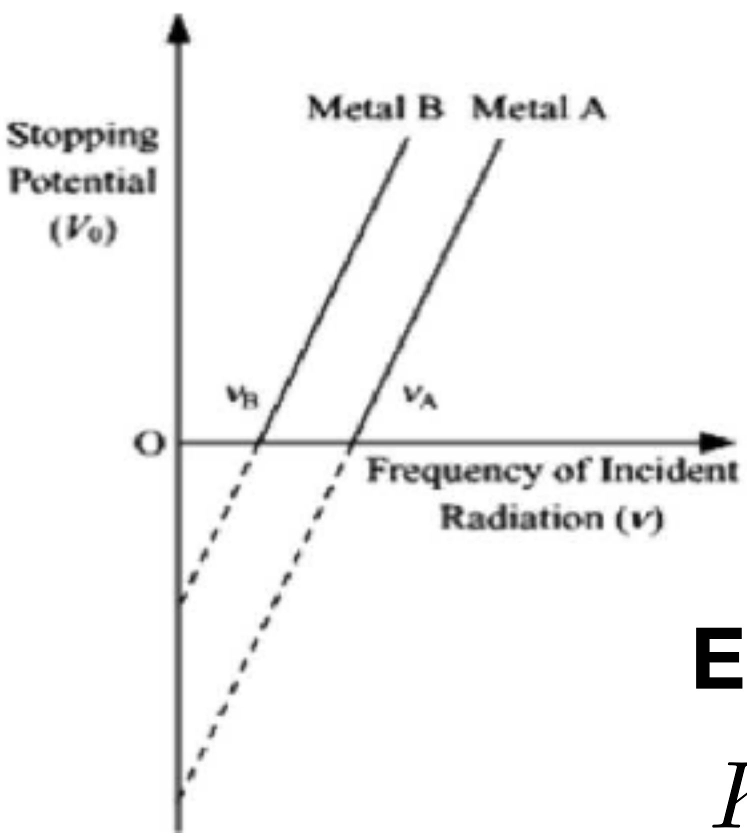
Max-Planck

Photoelectric Effect (1887-1905)





Heinrich Hertz



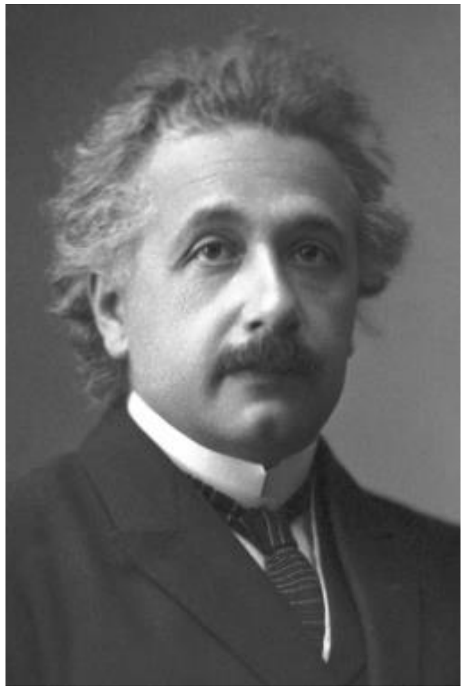
Failure of Classical theory of light: Frequency, NOT Intensity decides the threshold of photoelectron emission.

Einstein's quantization of Photon energy (1905)

$$K_{\max} = h\nu - \Phi_0 = h\nu - h\nu_0 = eV_0$$

$$K_{\max} = h(\nu - \nu_0)$$

Photoelectric Effect (1887-1905)



Albert Einstein, 1921

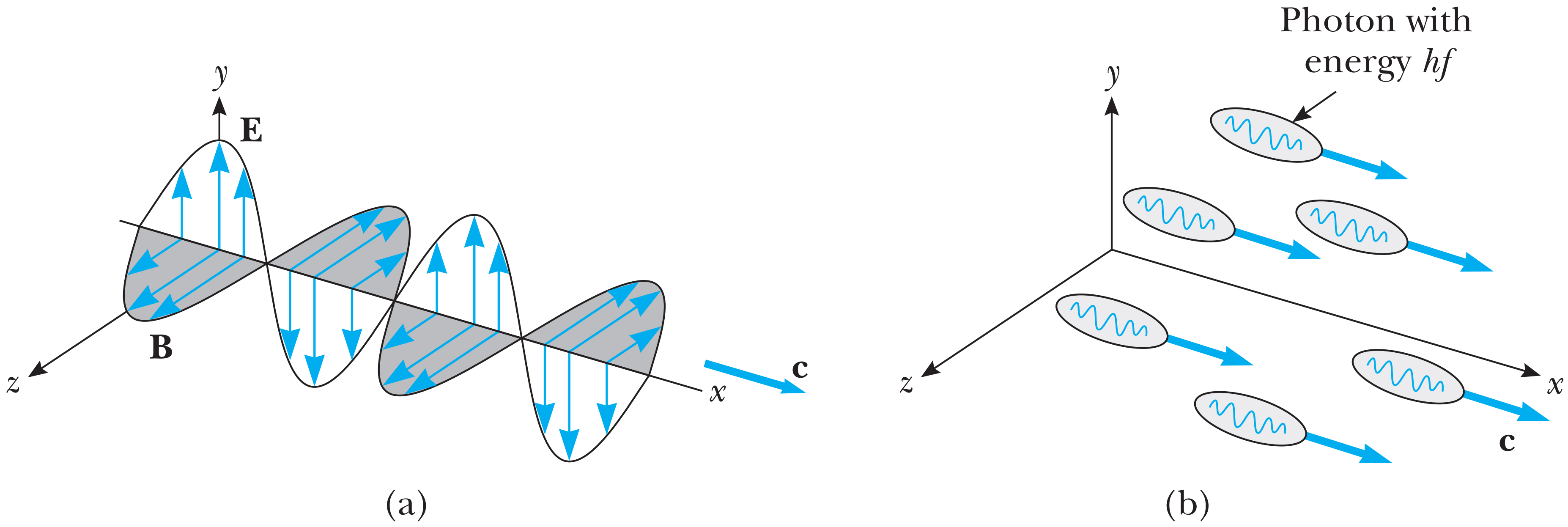


Figure 3.16 (a) A classical view of a traveling light wave. (b) Einstein's photon picture of "a traveling light wave."

Hydrogen Spectra (1888-1913)

Atomic Spectra of Hydrogen

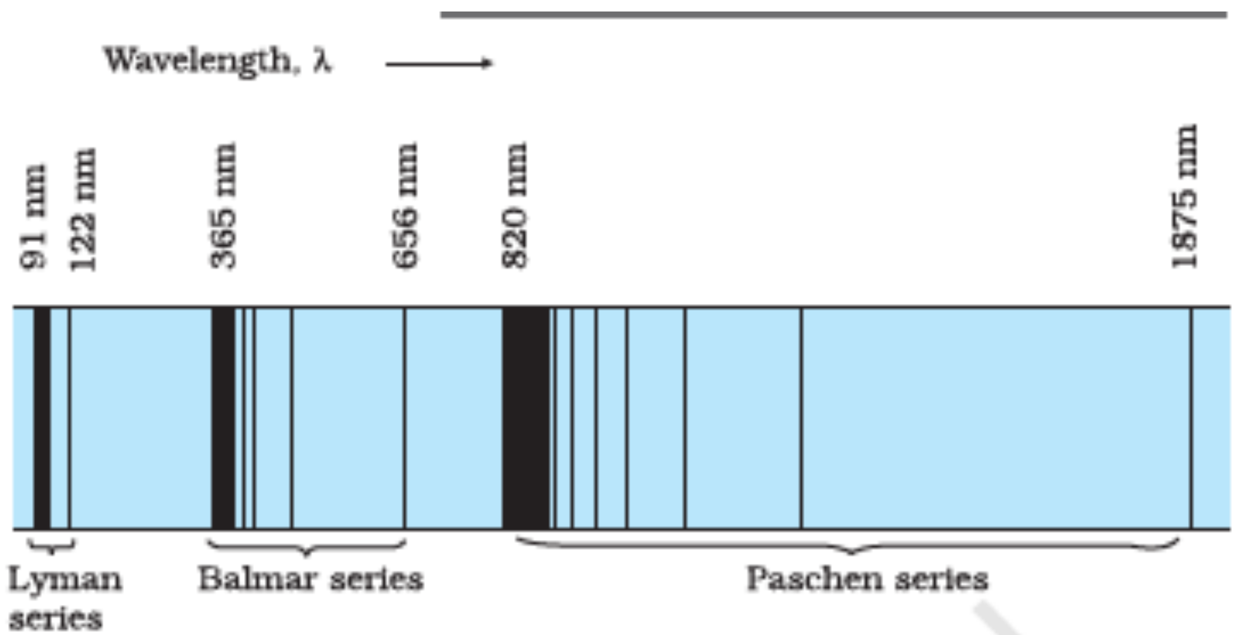
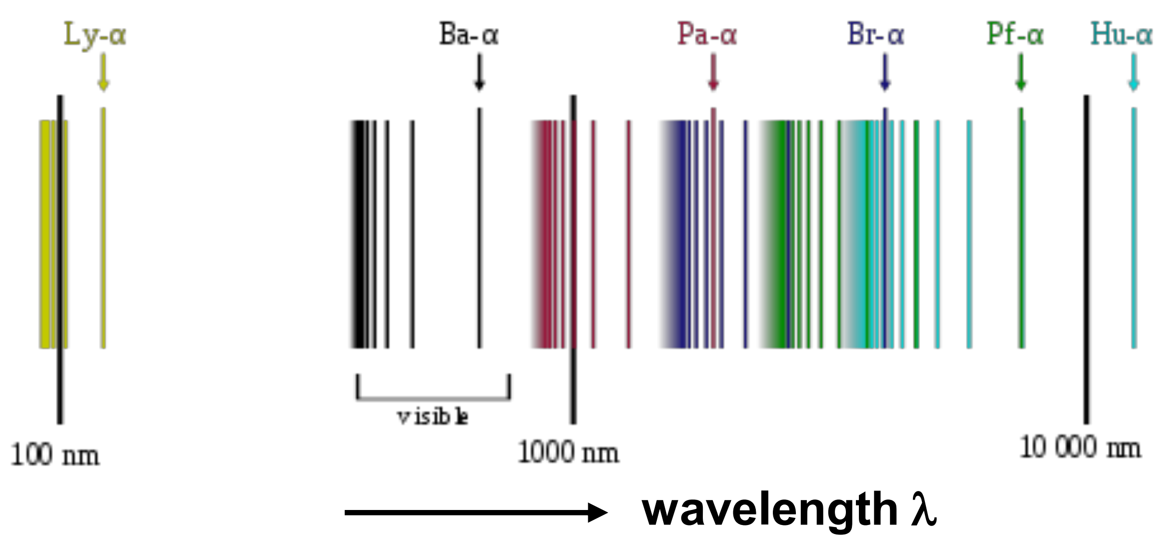


FIGURE 12.5 Emission lines in the spectrum of hydrogen.



Johannes Rydberg

$$\frac{1}{\lambda_{\text{vac}}} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \quad (1888)$$

Niels Bohr

Bohr model of Hydrogen atom (1913).

Recommended Readings

1. Black-body radiation, section 3.2 in page 68, and (optional) section 3.3 in page 77.

2. Photoelectric effect, section 3.4 in page 80.

3. The Bohr atom, section 4.3 in page 125.